



A Comparative Evaluation of Indonesia and China's Flood Risk Assessment and Disaster Risk Reduction Planning

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Abstract

Floods are the most frequent disasters caused by combinations of natural and anthropogenic factors. Given the increasing intensity and frequency of floods, especially in Asian mega-urban regions, effective Disaster Risk Reduction (DRR) strategies are critical. This study presents a comparative evaluation of the national flood risk assessment methods in Indonesia and China, followed by a flood risk map analysis calculated using the Chinese and Indonesian standards for flood risk assessment, specifically for a case study in Bandung City, Indonesia. We found that the Chinese standard method produces a broader spatial identification of high flood risk areas, influenced by rainfall intensity and topography, which better represents pluvial flood risks. Meanwhile, the Indonesian method produces localized high flood risk near rivers, which better represents fluvial flood risks. In the case study of Bandung City, the occurrence of pluvial floods was more dominant than fluvial floods. Therefore, the spatial accuracy of the Chinese method was slightly higher than the Indonesian method. The study emphasizes the importance of a national flood assessment method that balances accuracy, data availability, computational resources, and local/regional characteristics to cope with the increasing risk in urbanized flood-prone areas.

Keywords: Risk Assessment; Disaster Risk Reduction; Flood Hazard Map.

1. Introduction

Over the past decade, global flood risks have intensified significantly, driven by climate change and land-use change [1, 2]. Together with river training, the impact of climate and land-use changes on floods varies significantly for small to large catchments, as well as for short-duration and high-intensity rainfall versus long-duration and low-intensity rainfall and for low- to high-return-period rainfall [3]. Globally, daily maximum rainfall is increasing with temperatures, about 7% for every location [4, 5]. Due to climate change, intense rainfall becomes more intense in the future, with frequency ratios for strong events (e.g., 50-year return period) consistently larger than for the weak

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events (e.g., 10-year return period) [5]. Climate change also contributes to changes in rainfall duration and intensity [5, 6], higher annual extremes, higher flood quantiles, and higher flood volumes [7, 8]. Meanwhile, urbanization is one of the contributing factors to land use change, which reduces the pervious surface area and increases the flood risk [9].

Nevertheless, the impact of land use changes on floods is more pronounced in small catchments [3]. In a case study of Xiamen, a city on the southeastern coast of China, total runoff from the urban area almost doubled from 1985 to 2015, increasing from approximately 14% to approximately 28% [10]. In a case study of Jakarta, Indonesia, flooding from a combination of river flood, coastal flood, land subsidence, and sea level rise may surpass the existing coastal wall in the future and lead to more extensive flooding in the city [11]. In a case study of Nusantara Capital City, Indonesia, flood hazard has been increasing in the last few years due to the rapid infrastructure and land development near the location of the New Capital City of Indonesia [12]. In a case study of the Tianshan Mountains, China, flash flood risk is projected to increase from 2020 to 2030, and this risk in the future is likely affected by land use and land cover change compared to climate change [13]. The above studies show that many factors contribute to flood hazards, and flood severity is increasing in many regions, including Asia, from coastal cities to inland areas.

Floods affect human livelihood, both in the short and long term. In the short term, for example, floods may pose a direct negative impact on human health [14] and disrupt transportation networks [15]. In the long term, for example, floods may result in the displacement of people and deterioration of living conditions [14], and high cost of infrastructure maintenance [16]. Therefore, developing efficient strategies is important to mitigate further losses associated with floods [14, 16].

Disaster Risk Reduction (DRR) is a series of activities aimed at: 1) preventing new disasters; 2) reducing existing disaster risk; and 3) strengthening resilience against hazards [17]. Flood DRR encompasses policies, standards, and guidance to mitigate short-term disaster impacts as well as promote long-term disaster resilience. A combination of government initiatives and public participation is key to enhancing the effectiveness of DRR [18, 19]. Implementation of DRR might be different from one country to another. There might be no guarantee that the DRR standard in a country can be perfectly matched and applied to another country. Therefore, a comparative study of DRR is needed to evaluate the pros and cons of a method in capturing the local or regional flood conditions.

Indonesia and China are relevant case studies for flood disasters due to their diverse geographical and flood characteristics, flood infrastructure, and government approaches, which present unique challenges in flood management and disaster response. Bandung, one of the most populous cities in West Java Province, Indonesia, was picked as a case study. Differences in methodology, policies, regulations, and DRR implementations at the national level of Indonesia and the People's Republic of China were analyzed, followed by a more detailed flood risk assessment using both Indonesian and Chinese methods in a case study of Bandung City. The study analyzed the pros and cons of both methods to capture the actual flood spatial distribution and its risk in Bandung City.

The objective of this study is: 1) to compare national flood risk assessment methodologies, policies, and regulations in Indonesia and China; and 2) to evaluate the local impact of these frameworks through a case study of Bandung City. Comparing national flood risk assessment methodologies, policies, and regulations in Indonesia and China involves analyzing how each country approaches the identification, evaluation, and management of flood risks and how their policies and regulations are structured to mitigate flood impacts.

2. Materials and Methods

2.1. Study Area

Bandung City is the capital city of West Java Province, approximately located at 6.902°S and 107.619°E. Being one of Indonesia's most densely populated cities, with a population density of more than 13,000/km², and located in the flood-prone Bandung Basin illustrates the complexities of managing urban flood risks in this city. Rapid urbanization, poorly enforced zoning laws, poor solid waste management, illegal building, and inadequate drainage infrastructure have increased the city's vulnerability to flooding [20]. Historically, regions adjacent to the Citarum River have demonstrated heightened vulnerability due to their proximity to water bodies and inadequate flood management infrastructure. Consequently, recurring flooding incidents have significantly impacted local communities and infrastructure [21]. Bandung City's flood management still needs to be updated to address the inundation trend, city spatial plan, flood risk assessment, infrastructure enhancements, and community preparedness initiatives [21, 22]. Figure 1 shows the study location.

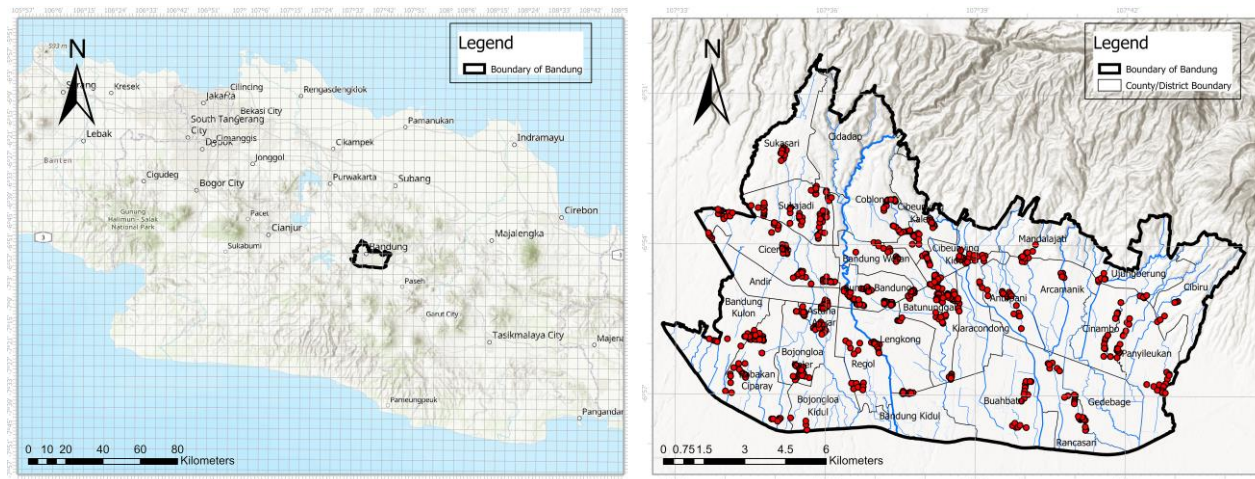


Figure 1. Study Location (left); Location of Flood Points Bandung City, Indonesia (right)

2.2. Framework for Flood Risk Assessment

2.2.1. Risk Assessment Frameworks

Flood risk assessment aims to establish where the risk is unacceptably high and where mitigation actions are necessary. The most common approach to defining flood risk is that it is the product of hazard and vulnerability [23]. A hazard is defined as a source of potential harm, a situation with the potential to cause damage, or a threat/condition with the potential to create a loss of lives or to initiate a failure of the natural, modified, or human systems [24]. On the other hand, vulnerability can be defined as a measurement of the degree of susceptibility to damage from this hazardous phenomenon or activity [24]. The vulnerability aspects consider the exposure of people and assets to floods and the susceptibility of the elements at risk of flood damage [25]. Based on this definition, meteorological, hydrological, and hydraulic investigations can be performed separately to define the hazard and estimate the flood impact, thereby defining the vulnerability. However, they must be combined for the final risk analysis [25].

2.2.2. Global Flood Risk Assessment Best Practice

Comprehensive flood risk assessments require analyzing critical points where risks increase or decrease, from initial weather conditions to points of vulnerability where impacts are felt [26]. An integrated understanding involves assessing the probability of flooding, related hazards, potential damages, and the vulnerabilities of impacted communities or regions. Whereas conventional evaluations typically begin with hydrometeorological data, a holistic perspective includes examining hydrological events, physical infrastructure, and non-structural approaches to determine suitable and effective interventions. However, increasing threats from climate change, population growth, and land-use changes complicate this process, diminishing the reliability of historical data for risk prediction [27]. The multi-criteria index system is the most widely used method for flood risk assessment, utilizing indicators such as slope, land use, precipitation, and population density to construct a multi-index system. It employs various methods, including subjective and objective weight determination, to quantify the index weights. The multi-criteria index evaluation method can flexibly select indicators according to regional characteristics and data availability and can flexibly select index quantification methods to evaluate flood risk. It is suitable for regions with different spatial scales and can intuitively reflect the relationship between each index and flood risk [28]. Many studies have shown that remote sensing technology can be a primary data source for GIS input, as demonstrated in Haq et al. [29]. Moreover, based on hydrological and hydrodynamic models, scenario simulation assessment is a method for dynamic simulation and assessment of disaster processes that can be applied in various study areas by designing disaster scenarios with specific frequencies and intensities [30]. Based on the one-dimensional hydraulic model, two-dimensional numerical models have been gradually promoted.

Southeast Asia is a region that frequently experiences floods, necessitating the evaluation of flood risk to enhance disaster emergency management [31]. Flood risk assessment in Southeast Asia employs various methods to address the region's high vulnerability to flooding. Studies have utilized the coefficient of variation and TOPSIS approaches to evaluate flood risks across eleven Southeast Asian countries, revealing Indonesia and Vietnam as high-risk areas [32]. Hydrological models and satellite-based rainfall data have been utilized to analyze flood features in river basins, with GSMaP data proving particularly helpful in supplementing existing flood forecasting systems [33].

2.2.3. Disaster Risk Reduction Policies and Regulations

The Flood Risk Assessment (FRA) is a comprehensive flood risk assessment that identifies all flood mechanisms, recommends flood mitigation measures, and provides guidance on actions to be taken before and during a flood. FRA is a crucial activity for understanding local flood risks and establishing a framework for implementing effective risk

reduction measures, thereby fostering resilient communities. FRA aligns with the Sendai Framework for Disaster Risk Reduction 2015–2030 priorities, particularly the priority, "Understanding Disaster Risk." This global framework emphasizes the importance of risk assessments in identifying hazards, vulnerabilities, and exposures as foundational steps in disaster risk management.

Globally, flood risk reduction efforts are supported by international and regional frameworks. The United Nations Office for Disaster Risk Reduction (UNDRR) is the United Nations (UN) agency leading the coordination of disaster risk reduction. UNDRR's goals are to help decision-makers worldwide better understand and respond to risk. UNDRR promotes the National Disaster Risk Assessment (NDRA) methodology, providing comprehensive guidance for evaluating disaster risks, including floods, to inform strategic management. In Europe, the European Commission's Risk Assessment and Mapping Guidelines for Disaster Management (2010) offer member states a regional framework for evaluating flood and other disaster risks [34]. However, regions such as Asia, including ASEAN, lack a unified framework for flood-specific risk assessments, resulting in a reliance on national-level strategies.

Flood risk management typically follows the broader disaster risk management cycle, which consists of prevention and preparedness in the pre-disaster phase and response and recovery in the post-disaster phase. Disaster Risk Reduction (DRR) aims to reduce the likelihood of disasters occurring. DRR focuses on several strategies to minimize risk, including pre-disaster efforts that emphasize preparedness and risk mitigation. The UNDRR defines DRR as a conceptual framework aimed at reducing societal vulnerabilities and hazards while promoting sustainable development. Flood risk assessment requires identifying potential flood hazards, analyzing their probability and characteristics (e.g., rainfall intensity, riverine overflow), and determining exposure and vulnerability. Risk is generally quantified as a function of hazard, exposure, and vulnerability. Flood hazards are often simulated by considering flood probability or return period and infrastructure development scenarios. The output may cover the potential inundation area and inundation depth. Advances in technology and tools, such as GIS-based platforms and software like HEC-RAS and FloodMap, have enabled the conduct of detailed flood risk assessments. These tools integrate hazard, vulnerability, and exposure data, offering insights at local, national, and global scales to guide flood risk reduction measures. Flood risk reduction efforts also benefit from grey infrastructure, such as levees, embankments, floodgates, retention ponds, and pumps, as well as non-structural strategies, including community-based early warning systems and urban planning regulations that consider flood hazards.

By incorporating global and regional frameworks and updated assessment tools into the long-term flood mitigation plan, policymakers can have a clear pathway to reduce flood risks and future disasters.

2.3. Framework for Comparative Study of Flood Risk Assessment in China and Indonesia

2.3.1. Mathematical Framework

This study adopts the global disaster risk concept developed by the UNDRR (2015) and reflected in the Sendai Framework for Disaster Risk Reduction 2015-2030, which defines risk as the interaction between vulnerability, capacity, exposure of persons and assets, hazard characteristics, and the environment. This conceptual basis provides the foundation for comparing how national flood risk assessments in China and Indonesia operationalize these components.

Flood risk assessment in China employs a multiplicative model, using three indices: hazard, vulnerability, and exposure. The Equation is shown in Equation 1:

$$FRI = (\sum_{i=1}^n H_i h_i) + (\sum_{i=1}^n V_i v_j) + (\sum_{i=1}^n E_i e_k) \quad (1)$$

Where FRI is the flood risk index; H is the hazard index; V is the vulnerability index; E is the exposure index; and h_i , v_j , e_k are the weight values of hazard, vulnerability, and exposure index, respectively. This multiplicative approach emphasizes that risk only exists if all three components are present, where weighting factors influence the production of higher risk scores.

In comparison, Indonesia's BNPB framework extends this model by incorporating the capacity index as a moderating factor, as shown in Equation 2:

$$FRI = \frac{(\sum_{i=1}^n H_i h_i) \times (\sum_{i=1}^n V_i v_j)}{(\sum_{i=1}^n C_k c_k)} \quad (2)$$

Where FRI is the flood risk index; H is the hazard index; V is the vulnerability index; C is the capacity index; and h_i , v_j , c_k are the weight values of hazard, vulnerability, and capacity index, respectively. This modification reflects the Sendai Framework's emphasis on community and institutional capacity as a key element in reducing disaster risk. Therefore, while both frameworks share the same theoretical foundation, the Indonesian approach introduces a capacity-based judgement that highlights resilience as a core component of the national DRR strategy.

A comparison between the flood risk assessment methodology in China and Indonesia is shown in Figure 2.

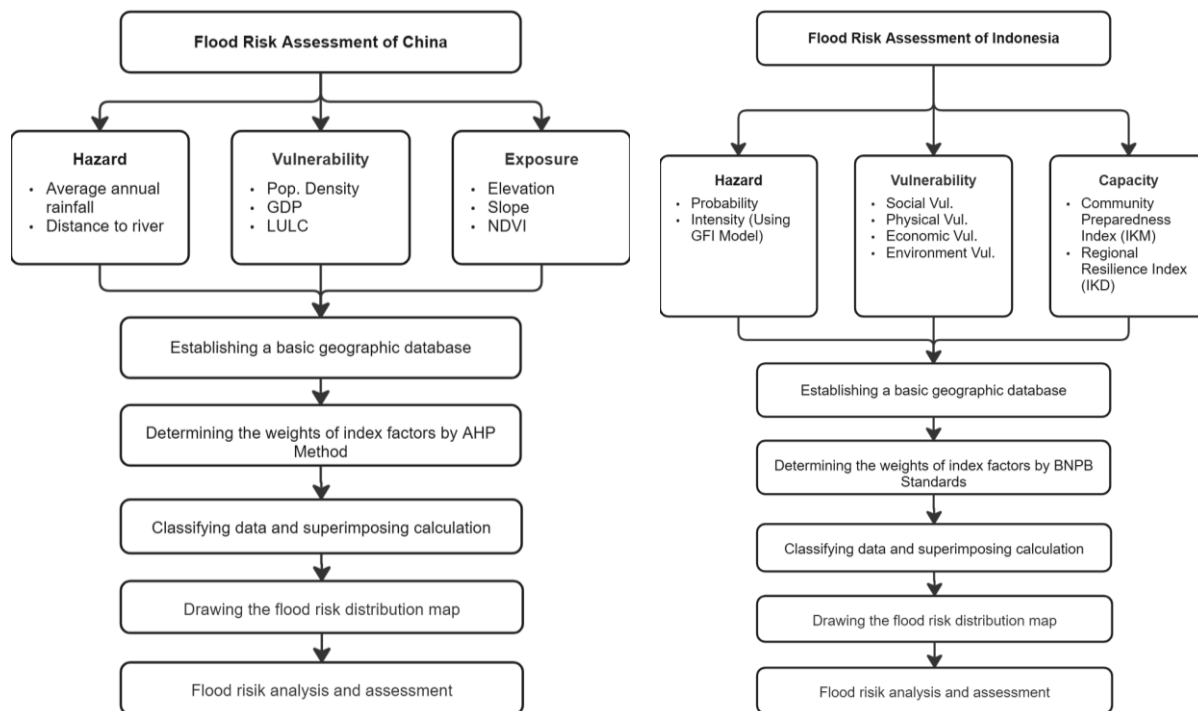


Figure 2. Comparison between flood risk assessment methodologies in China and Indonesia

2.3.2. Evaluation of Standard Flood Assessment Practices in Indonesia

Indonesia's disaster risk reduction (DRR) framework has undergone significant evolution since the catastrophic 2004 earthquake and tsunami. Following this event, the government initiated key legislative and institutional reforms to enhance disaster management capabilities. The enactment of Law No. 24 of 2007 on Disaster Management marked a pivotal shift, decentralizing disaster management responsibilities to local governments and mandating the establishment of disaster management agencies at the regional level. This law also provided the foundation for the creation of the National Disaster Management Agency (BNPB) in 2008, replacing the National Coordinating Agency for Disaster Management (Bakornas PB). BNPB coordinates national disaster management efforts, including flood risk reduction

At the provincial and municipal levels, the Regional Disaster Management Agencies (BPBD) act as extensions of BNPB, facilitating localized disaster management and risk reduction initiatives. Despite these structures, challenges persist in integrating disaster risk assessments into planning processes, particularly in flood-prone areas. Regulatory gaps limited technical capacity, and inconsistent budget allocations often hinder the effectiveness of DRR initiatives at the local level.

Flood risk reduction in Indonesia is guided by BNPB regulations, including Regulation No. 2 of 2012, which provides a framework for identifying risks, conducting vulnerability analyses, and assessing capacities. However, significant disparities exist in the implementation of these guidelines across regions. For example, while cities like Jakarta, Yogyakarta, and Semarang have adopted sophisticated flood risk mapping and early warning systems, other areas, such as Bandung City, face challenges in enforcing zoning regulations and land-use controls, and inadequate drainage system capacity, which exacerbates flood exposure.

2.3.3. Evaluation of Standard Flood Assessment Practices in China

In 2004, the PRC government requested technical assistance from the Asian Development Bank (ADB) to prepare a national flood management strategy (NFMS). The framework proposed relies on a risk management concept. Flood hazard is modified mainly by structural measures (e.g., dikes, dams, and diversions). However, upper watershed management also plays an important role in mitigating sediment deposition and waterway instability by reducing soil erosion and fluvial sediment transport. Land use controls can best manage exposure to flood hazards in more developed parts of river basins. A range of non-structural measures, such as flood forecasting and warning, and flood mapping, can modify the vulnerability of people and assets to exposure. China employs a fundamentally different mathematical framework for flood risk assessment compared to Indonesia, utilizing a multiplicative model that emphasizes the interdependence of risk components. The Chinese standard assessment method calculates flood risk using the equation: $FRI = H \times V \times E$, where FRI represents the flood risk index, H is the hazard index, V is the vulnerability index, and E is the exposure index. This multiplicative approach reflects an underlying assumption that risk only exists if all three components are present simultaneously, creating a framework where the absence or minimal presence of any single

component significantly reduces the overall risk calculation. China's flood risk assessment methodology has been developed independently, tailored to address the country's specific geographical, climatic, and institutional characteristics rather than adhering to standardized regional protocols. In China, a multi-criteria index system has been applied, such as in the Jiulong River watershed, to evaluate flood risk by integrating hazard, exposure, and vulnerability factors in order to assess spatiotemporal flood risk dynamics, considering 23 indicators such as peak discharge, daily rainfall, and land use changes which highlights how different factors contribute to flood risk in not only specific areas, but also in different periods [35]. In addition, two-dimensional hydraulic model has been conducted by the China Institute of Water Resources and Hydropower Research, which can accurately simulate the evolution of surface floods during the entire rainfall process which can accurately simulate the evolution of surface floods during the entire rainfall process. An equivalent drainage model based on manholes is also proposed to simulate urban flooding using the two-dimensional hydrodynamic model [36].

In the multi-criteria index system, the selection of indicators is limited by factors such as data availability, the characteristics of the study area, and data accuracy. At the same time, the determination of weights is influenced by the analysis method. Currently, the weight calculation method is primarily based on expert knowledge and experience, resulting in subjective evaluation results for the multi-index evaluation method [28].

2.3.4. Comparative Approaches to DRR between Indonesia and China

Comparative approaches of DRR between Indonesia and China are shown in Table 1.

Table 1. DRR comparative approaches between Indonesia and China

Aspect	Indonesia	China
National Governance Structure	Decentralized governance with local disaster management led by the National Disaster Management Authority (BNPB) and local agencies (BPBD) [37].	Decentralized governance with local disaster management led by the National Disaster Management Authority (BNPB) and local agencies (BPBD) [37].
Policy Framework	Integrates disaster risk reduction (DRR) into national policies, aligning with the Sendai Framework and Sustainable Development Goals [38]	Integrates disaster risk reduction (DRR) into national policies, aligning with the Sendai Framework and Sustainable Development Goals [38]
Risk Perception	Limited systemic risk awareness: communities often lack understanding of the root causes of vulnerabilities [37]	Limited systemic risk awareness: communities often lack understanding of the root causes of vulnerabilities [37]
Resource Allocation	Utilizes a mix of government budgets and innovative financing strategies like Disaster Risk Financing and Insurance (DRFI) [38].	Utilizes a mix of government budgets and innovative financing strategies like Disaster Risk Financing and Insurance (DRFI) [38].
Community Involvement	Strong emphasis on community participation in disaster preparedness through local training programs [37].	Strong emphasis on community participation in disaster preparedness through local training programs [37].
Early Warning Systems	Developed multiple early warning systems for various hazards, including MEWS and InaTEWS for tsunamis [38]	Developed multiple early warning systems for various hazards, including MEWS and InaTEWS for tsunamis [38]

3. Results and Discussion

3.1. Comparison of the Data Sources of the Detailed Flood Risk Assessment of Bandung City

In China's standard method, a flood risk assessment was conducted using GIS by analyzing the factors of physical geography and social conditions in Bandung. The hazard index consists of annual rainfall and distance to the river; the vulnerability index consists of population density, age ratio, land use/land cover, road density, and hospital density; and the exposure index consists of elevation, slope, and Normalized Difference Vegetation Index (NDVI). Each of the three indices has a weight that can affect the calculation of the flood risk index and is determined through the AHP process. In addition, all data is processed in raster form with standardized spatial resolution (2.5 x 2.5 m) to have an apple-to-apple comparison. For a case study of Bandung City, data for flood risk assessment using China's index factors are shown in Table 2.

Table 2. Detailed information on each of China's index factors

Index	Factor	Data source	Format
Hazard	Average annual rainfall	Calculated from elevation data	Raster (.tif)
	Distance to the river		
Vulnerability	Population density	Bandung city government (https://opendata.bandung.go.id/dataset)	Dataset (.csv)
	Age ratio	Bandung city government (https://opendata.bandung.go.id/dataset)	Dataset (.csv)
	Land use/land cover	Dynamic world (https://dynamicworld.app/)	Raster (.tif)
	Road density	Indonesian Geospatial Information Agency (https://www.big.go.id/)	Polyline (.shp)
	Hospital density	Bandung city government (https://opendata.bandung.go.id/dataset)	Polyline (.shp)
Exposure	Elevation	LiDAR of Bandung	Raster (.tif)
	Slope	LiDAR of Bandung	Raster (.tif)
	NDVI	MODIS Vegetation Index Products (https://modis.gsfc.nasa.gov)	Raster (.tif)

According to the study on the urban flood risk assessment system of Zhengzhou City, the weights assigned to each index are hazard weight 0.39, vulnerability weight 0.13, and exposure weight 0.49 [39]. Most of China’s flood risk assessment uses the same approach as the AHP method. The Zhongzhou city, which is the referenced city, has the same physical characteristics as Bandung city. The city is crossed by many rivers and strongly influenced by the annual rainfall. The same applies to the vulnerability judgment of the city, which is highly influenced by GDP and followed by population density.

Nearly all the required data needs are included in China's standard approach for the Indonesian standard flood assessment method. However, certain aspects, such as the flood index obtained by the river capacity and morphology approach (Geomorphic Flood Index-GFI Method), and NDVI, are included in vulnerability and categorized as ecological influences. For a case study of Bandung City, a list of data for flood risk assessment using China's index factors is shown in Table 3.

Table 3. Detailed information on each of China's index factors

Index	Factor	Data source	Format/Output
Hazard	Flood Depth	Calculated using the GFI Method using topographic data (LiDAR), river network map, and watershed boundary map from the Indonesian Geospatial Information Agency (https://www.big.go.id/)	Raster (.tif)
	Social Vulnerability	Included population density, age ratio, and specific demographic ratio from the Bandung city government (https://opendata.bandung.go.id/dataset)	Raster (.tif)
Vulnerability	Physical Vulnerability	Housing density, public facilities density (education, health, government, etc.), and critical facility density from the Indonesian Geospatial Information Agency (https://www.big.go.id/)	From point (.shp) file to Raster (.tif)
	Economic Vulnerability	Productive land density from the Geospatial Information Agency (https://www.big.go.id/)	From point (.shp) file to Raster (.tif)
	Environment Vulnerability	Ecological Index using NDVI from MODIS Vegetation Index Products (https://modis.gsfc.nasa.gov)	Raster (.tif)
Capacity	Community Preparedness Index (IKM)	From the participatory focus group discussions with city government, NGOs, and community representatives, using structured questionnaires, followed by data verification.	
	Regional Resilience Index (IKD)	From the survey activities to assess the readiness of local communities	

3.2. Comparison of the Standard Flood Assessment Method of China and Indonesia in a Case Study of Bandung City

3.2.1. Hazard Index Map

The Hazard Index Map, which resulted in the Chinese standard flood assessment method and the Indonesian flood assessment method, for a case study of Bandung City, is shown in Figure 3.

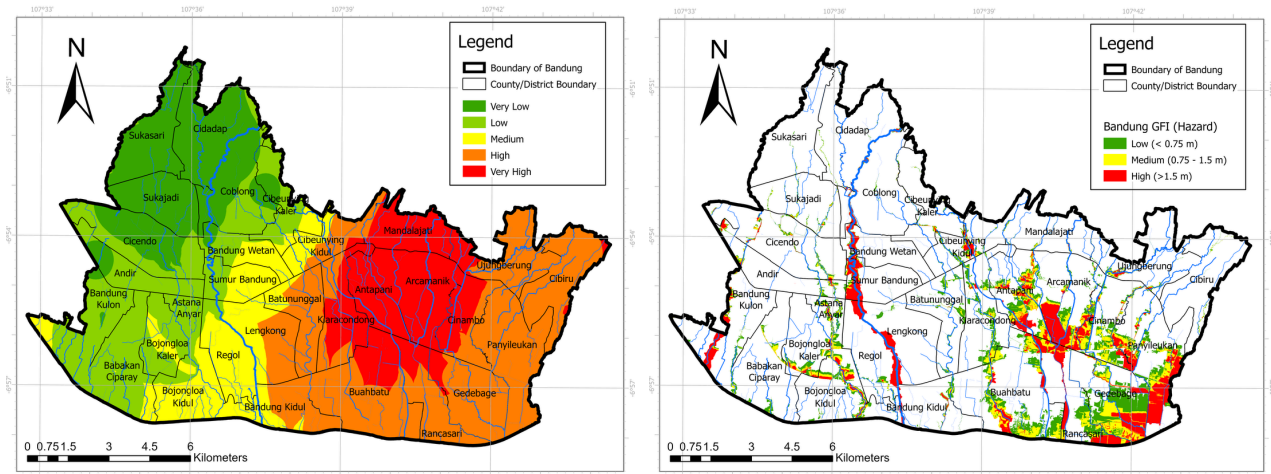


Figure 3. Hazard index map of Bandung City, calculated using the Chinese standard flood assessment method (left) and using the Indonesian standard flood assessment method (right)

The hazard index map is expected to match the actual flood-prone area. In China's standard approach, the hazard index is calculated mainly based on annual rainfall and the distance from the main channel or rivers. The left figure shows that high rainfall was concentrated in the eastern part of Bandung City, such as in the Sub-Districts of Mandalajati, Antapani, Arcamanik, Kiaracandong, Cinambo, Buahbatu, and Gedebage. Some river tributaries that flow through these subdistricts resulted in a high flood hazard index.

The correct figure shows that the high hazard index is mainly concentrated in the area adjacent to the river, indicating the typical flow accumulation affected by topographical features, which leads to fluvial flooding. Some areas in the central part of the city, such as the sub-districts of Bandung Wetan, Sumur Bandung, Lengkong, and Regol, were considered to have a high index since one of the main rivers in Bandung (Cikapundung River) flows through these areas. A high index can also be observed in the eastern part of Bandung City, consistent with the results of flood risk assessments using China's standard approach.

3.2.2. Vulnerability Index Map

The Vulnerability Index Map resulted in the Chinese standard flood assessment method, and the Indonesian flood assessment method for a case study of Bandung City is shown in Figure 4.

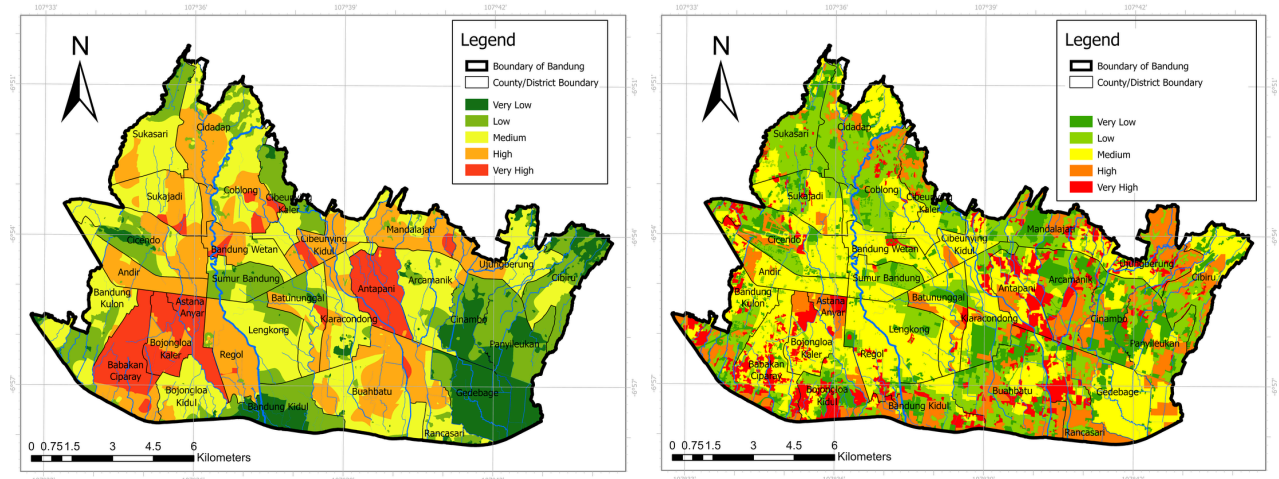


Figure 4. Vulnerability index map of Bandung City calculated using the Chinese standard flood assessment method (left) and the Indonesian standard flood assessment method (right)

Figure 4 shows that the vulnerability index resulting from flood risk assessment using the Indonesian standard varies slightly in smaller patches compared to the result of the Chinese standard method. This difference resulted from the use of more detailed socio-demographic and physical infrastructure density data in the Indonesian standard method.

However, both maps have relatively similar trend locations with a high vulnerability index in the areas around the southwest part of the city, such as the sub-districts of Bojongloa Kaler, Astana Anyar, Bandung Kulon, Andir, and Babakan Ciparay, and the east part, such as the sub-districts of Antapani, Kiacacondong, Mandalajati, and Ujungberung.

3.2.3. Exposure Index Map

The exposure calculated using the Chinese standard flood assessment method, for a case study of Bandung City, is shown in Figure 5.

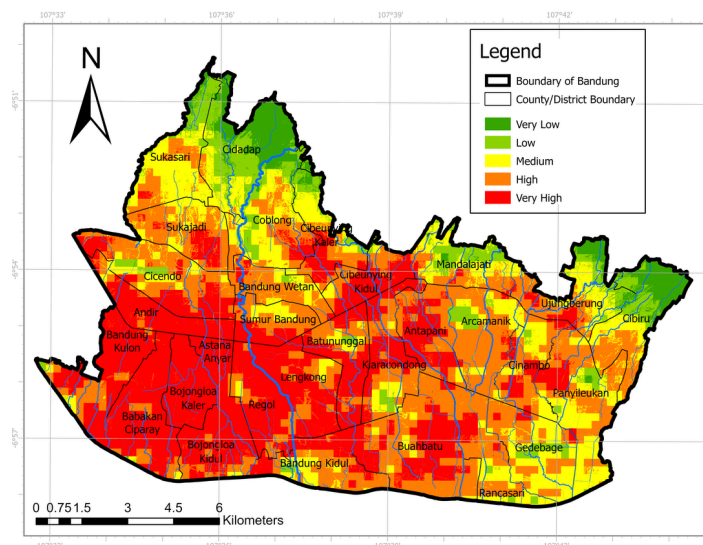


Figure 5. Exposure index map of Bandung City

The exposure index has been shown to be relatively high in the southwest part of the city. It is the result of the combination of NDVI value, low elevation, and mild topographical slope.

3.2.4. Capacity Index Map

The capacity index calculated using the Indonesian standard is shown in Figure 6.

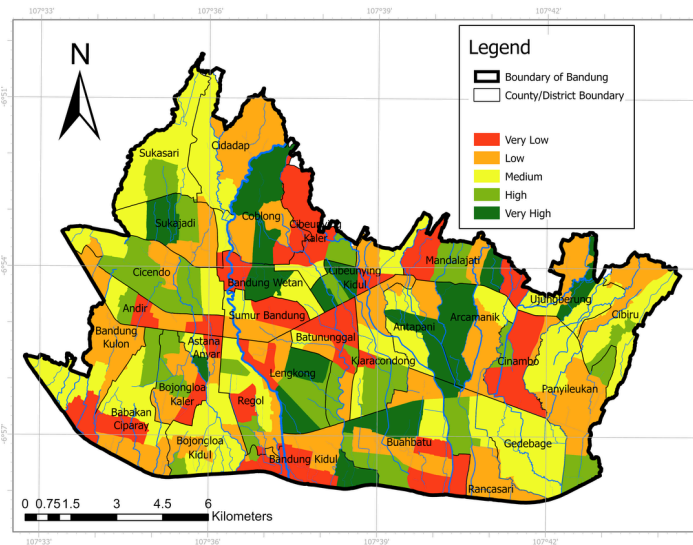


Figure 6. Capacity index map of Bandung City

The capacity index is shown to be relatively distributed, with a patch of high index; these data were acquired based on one-time surveys for every sub-district in Bandung City. The methodology of the survey started with a general introduction of this flood risk assessment activity in the sub-district hall, followed by the filling of the questionnaire by the participants. The results of these surveys show spatial differences between sub-districts that depict the disaster preparedness and mitigation programmes.

3.2.5. Flood Risk Index Map

The flood risk index map, calculated using the Chinese standard flood assessment method and the Indonesian standard flood assessment method for a case study of Bandung City, is shown in Figure 7.

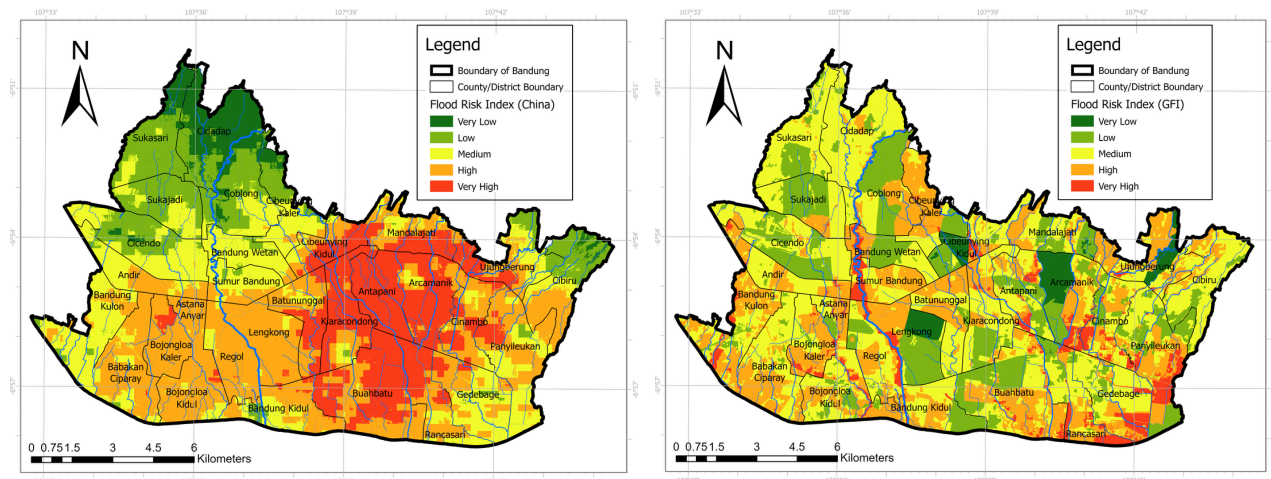


Figure 7. Flood risk index map of Bandung City calculated using the Chinese standard flood assessment method (left) and the Indonesian standard flood assessment method (right)

Figure 7 Shows that the Chinese flood assessment method resulted in a significantly large area with high flood risk in Bandung City, especially in the central and eastern parts of the city, such as in the sub-districts of Buahbatu, Arcamanik, Antapani, Rancasari, and Gedebage District. The high flood risk index in these areas is mainly affected by high rainfall intensity and low topography. Meanwhile, the southwest part of the city shows relatively high flood risk, primarily due to its high population density. In contrast, the Indonesian flood assessment method resulted in more localized high flood risk near the main river. This localized high flood risk area is mainly affected by the distance to the main river and the low topographical features of the floodplain.

3.3. Discussion

3.3.1. Flood Risk Map and Flood Point Locations

To compare the results, data that validates the results is required. The validation data used is flood historical point data based on survey results. It will show a disparity in flood risk prediction accuracy between Chinese and Indonesian (GFI) methodologies. A comparison between flood risk assessment and flood points is shown in Figure 8.

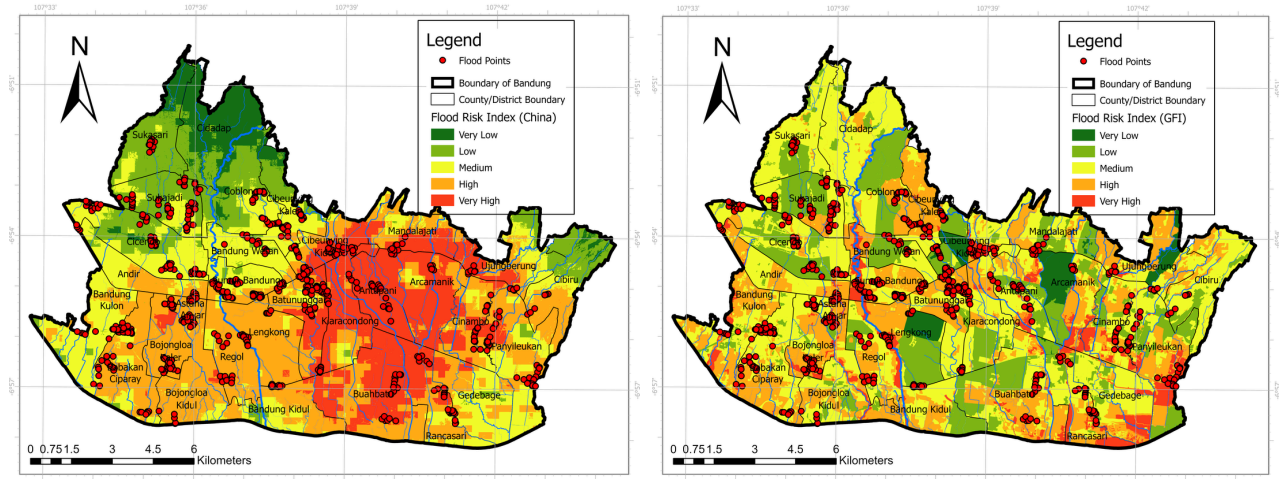


Figure 8. Comparison between the flood risk index map and flood points in Bandung City, calculated using the Chinese standard flood assessment method (left) and the Indonesian standard flood assessment method (right)

The Chinese method achieved a markedly higher validation rate of 73.16%, while the Indonesian method achieved 66.84%. Analysis of the 737 flood points revealed distinct distribution patterns across risk categories, as shown in Table 4.

Table 4. Detailed Information on the Validation Result

Risk Category	Indonesian Method	Chinese Method	Combined Method
1 (Very Low)	7	0	0
2 (Low)	118	92	31
3 (Medium)	292	189	151
4 (High)	248	327	363
5 (Very High)	72	129	192
Total	737	737	737
Validation Rate	66.84%	73.16%	79.21%

The Chinese methods showed a concentration in medium-high-risk categories with 129 points (17.50%) in category 5, 327 points (44.37%) in category 4, and 189 points (25.64%) in category 3, indicating stronger predictive capability for actual flood events. Since the model assigns relatively high weights to rainfall in the hazard components (0.39) and to topography within the exposure components (0.49), its outputs align with the flood points along Bandung’s central-eastern corridor, an area of flat terrain and constrained drainage. These zones are also dominated by dense residential development, which increases impervious cover, amplifies surface runoff, and raises exposure. Considering that the very-high-risk areas lie predominantly within this corridor, the results underscore Bandung’s pluvial-flood dominance driven by the combination of high imperviousness and limited conveyance.

The Indonesian method placed 72 points (9.77%) in the highest category (5), 248 points (33.65%) in category 4, and 292 points (39.62%) in category 3. Compared to the Chinese method, this approach produced a lower overall validation rate and a narrower spatial concentration of high-risk areas. Since the Indonesian uses a GFI-based model, which emphasizes river proximity and floodplain extent as primary hazard components, the results highlight high-risk zones mainly along the southern and eastern corridor of Bandung, particularly near the Cikapundung River and its tributaries.

There are two standard terms in hydrology and disaster risk management that classify types of flood hazards: pluvial flood and fluvial flood. Pluvial floods refer to the inundation resulting from rainfall-generated overland flow before the main channel, a typical inundation in an area with poor drainage. Meanwhile, a fluvial flood refers to a condition where inundation results from river overflow. The Chinese method relies heavily on average annual rainfall, topographic

characteristics, and land use. It highlights broader urban areas with low infiltration capacity, resulting in a high potential for runoff. This approach is particularly suitable for assessing risk in cities with poor drainage systems or heavy rainfall patterns, where fluvial flooding is a major concern.

On the other hand, the Indonesian GFI-based method focuses more on spatial proximity to flood-prone zones along riverbanks, thus emphasizing fluvial flooding. It identifies localized flood risk concentration near the river. The method is suitable for mapping river-driven flood events and is more sensitive to the hydrological behavior of the river network.

Flood inundation in Bandung City is primarily caused by pluvial floods, which are significantly influenced by inadequate local drainage infrastructure. Fluvial floods in Bandung City are limited to a few locations, primarily caused by a reduction in the river or main channel capacity due to insufficient culvert dimensions or clogs from solid waste. A combination of flood risk assessments covering both pluvial and fluvial floods may be necessary for an area like Bandung City, where both types of floods typically occur. However, a more detailed analysis might also affect data requirements and computing resources. The Indonesian standard flood assessment method might be suitable for a typical case where most floods occur due to river overflow and flood protection infrastructure in the riverbank (e.g., flood embankment) is insufficient.

Meanwhile, the Chinese standard flood assessment method may be suitable where the infrastructure in the riverbank is mostly adequate to prevent fluvial flooding and inundation tends to occur locally due to high rainfall intensity. For most Indonesian cases, the Indonesian flood assessment method might be sufficient. However, enhancing the flood assessment method to cover a broader range of flood types may become urgent to accommodate more complex city developments, such as those in Bandung City. Other factors, such as the local hazard situation, engineering design parameters, and national building codes, also need to be considered to cope with more frequent and intense disasters in the future [40, 41].

A combination of both approaches is attempted to demonstrate how both cover each other's gaps. By creating an algorithm, the index values in each method must be overlaid and the maximum value determined. The maximum value used from both will be taken as the basis for index retrieval in the combined layer. The results were excellent, marked by an improvement over the previous best value, which was the Chinese Method (73.16%), with the combined method reaching 79.21%.

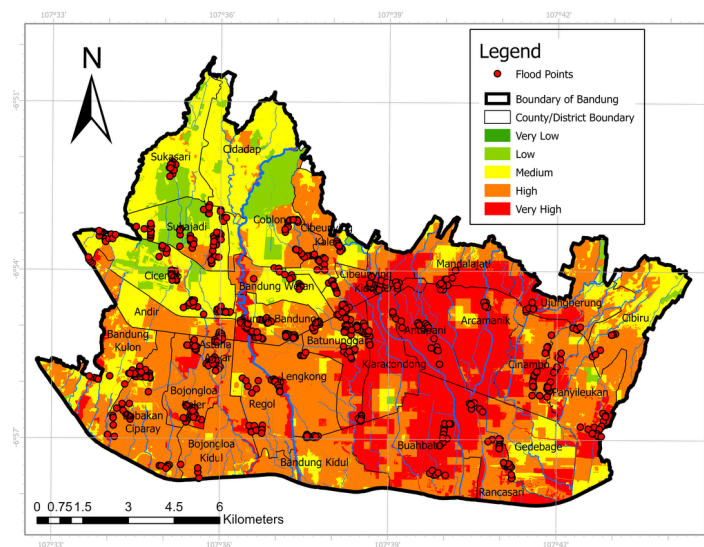


Figure 9. The Combined Flood Risk Index Method (Indonesia-China)

3.3.2. Policy Approach Framework

In Indonesia, flood risk assessment often combines meteorological data, hydrological models, and local knowledge to evaluate flood-prone areas, as seen in [42-44]. The country's decentralized governance system can lead to regional disparities in flood management, with some river basin organizations or local governments having stronger frameworks for managing flood risk than others. Indonesia's flood policies focus on early warning systems, infrastructure improvements, and community-based disaster preparedness. The National Disaster Management Agency (BNPB) plays a crucial role in coordinating responses, although the country's relatively fragmented approach can complicate disaster management at the local level. Regulations emphasize disaster response, but long-term risk reduction strategies are still evolving [45]. However, due to regional autonomy, policy implementation can vary across provinces and river basin territories. Local governments often lead initiatives with support from national agencies, leading to inconsistencies in flood resilience outcomes.

In contrast, China adopts a more centralized approach to flood risk management, with the government utilizing sophisticated risk assessment methodologies based on hydrological modeling, satellite data, and integrated water resources management. The Chinese government has invested significantly in large-scale infrastructure projects, including flood control dams, dikes, and river management systems, particularly in flood-prone areas such as the Yangtze River Basin. Flood risk policies are framed under national strategies such as the “National Flood Control and Drought Relief Plan,” and regulations are strictly enforced, often prioritizing technological solutions and state-driven initiatives. China’s flood risk management is also heavily integrated with urban planning, where local governments implement flood protection measures tailored to specific regional needs. In recent years, China’s flood disaster policies shifted from grey infrastructure to more integrated grey-green infrastructure and flood management [46].

Comparing the two countries, Indonesia’s approach is more focused on localized disaster management with a growing emphasis on community-based initiatives. Meanwhile, China’s methodology relies on top-down, grey-green infrastructural projects, stringent regulations, and flood management. Both countries, however, face challenges in balancing rapid urbanization with flood risk mitigation, and there is increasing recognition in both nations of the need for more comprehensive, sustainable flood management strategies that integrate environmental and social considerations.

3.3.3. Regulatory Approach Framework

As a follow-up to disaster regulations at the central government level, the Bandung City Government has established several related regulations, including Bandung City Regional Regulation Number 3 of 2022, which focuses on the prevention and management of fire and disaster hazards. This regulation provides a comprehensive framework for implementing fire prevention and management strategies. It also outlines procedures for evacuation during non-fire emergencies. For example, Article 65 addresses evacuation during floods, which the City Fire Department is authorized to conduct. Additionally, Article 72 states that the City Government is responsible for overall disaster management, including disaster risk reduction efforts. Article 81 details the planning process for disaster management, which encompasses identifying and assessing potential disaster threats, understanding community vulnerabilities, analyzing the likely impacts of disasters, selecting appropriate risk reduction measures, determining preparedness and management mechanisms for disaster impacts, and assigning tasks, authorities, and resources. However, it’s important to note that while these regulations provide general guidelines for addressing potential disasters, they do not specifically address flood disasters.

3.3.4. Local Impact and Implementation: Bandung City Case Study

The City Government has information on potential flood locations throughout Bandung. As noted in Setiadi et al. [20]. The implementation of disaster risk reduction policies, particularly those addressing flooding, faces several challenges. These include land conversion, solid waste management, inadequate drainage infrastructure, and illegal encroachments along riverbanks by residents. In response, the city government has been developing various flood control infrastructures, including retention ponds and pump systems, and improving the drainage capacity. However, due to the complex factors, including socio-economic and cultural factors, effective flood management in Bandung cannot be conducted only by the government agency. Active involvement from multiple stakeholders supported by the Penta-helix Scheme, which encourages participation from government entities, academic institutions, the business sector, local communities, and the media, is needed.

4. Recommendations

Based on our comparative analysis and the Bandung case study, we propose critical and actionable recommendations for reducing flood risk. The findings reveal that Bandung’s risk profile is a complex mix of fluvial (river-based) and pluvial (rainfall-driven) flooding, with pluvial risk being the dominant and more widespread threat. Therefore, our primary recommendation is that Indonesia’s disaster management agencies (BNPB and BPBD) adopt a hybrid assessment framework. This new standard should integrate the strengths of the Indonesian (GFI-based) method, which excels at identifying localized fluvial risk, with the Chinese (rainfall/topography-based) method, which better captures the broad spatial risk from pluvial flooding. This combined model is not just theoretical; our study validated its superior predictive power at 79.21% accuracy. This hybrid framework must be used to generate new, high-resolution, official flood risk maps for Bandung. These maps are the essential foundation for subsequent policy and planning. They should be used to inform specific, technical revisions to local disaster regulations (e.g., Bandung City Regional Regulation No. 3 of 2022) and to strategically guide infrastructure investment. Efforts must prioritize pluvial flood mitigation, particularly upgrading urban drainage capacity in the high-risk central-eastern corridor (e.g., Sub-Districts of Buahbatu, Arcamanik, Antapani, and Gedebage). This “grey” infrastructure work must be supported by integrated water management, including robust solid waste programs to prevent drainage clogs, the development of “blue-green” infrastructure (like retention ponds and green open spaces), and the strict enforcement of spatial planning laws to prevent further land conversion and illegal riverbank encroachment.

Effective implementation of these technical solutions hinges on a multi-stakeholder approach. We recommend the Bandung City Government formalize and activate the "Penta-helix" framework, which our study identified as a key local strategy. This ensures continuous and synergistic collaboration among government agencies, academic institutions (such as ITB), the business sector, local communities, and the media throughout all phases of DRR planning and execution. This collaborative effort must be supported by enhancing future research and data collection. We recommend establishing a permanent system for continuous, high-resolution monitoring of critical variables, including rainfall intensity, real-time land-use changes, and socio-economic vulnerability. This data is essential for developing more dynamic risk models that move beyond static maps and allow for adaptive, long-term planning. Finally, to better measure and build societal resilience, the Indonesian method's community capacity indices (IKM and IKD) must be refined. We recommend that these capacity surveys be conducted more regularly (e.g., annually) and at a finer spatial resolution (e.g., *at the kelurahan or RW level, rather than the sub-district level*) to capture a more accurate and dynamic picture of community preparedness. This granular data will, in turn, allow for the design and deployment of more effective, localized, and targeted community-based preparedness programs.

5. Conclusion

This study conducted a comparative evaluation of the national flood risk assessment standards of Indonesia and China, applying both methodologies to a case study in Bandung City. Our findings reveal a critical divergence: the Indonesian GFI-based standard excels at identifying localized *fluvial* (river-based) flood risk, while the Chinese standard, prioritizing rainfall and topography, more accurately captures the widespread *pluvial* (rainfall-driven) risk, which is the dominant flood type in Bandung. This was validated against 737 historical flood points, where the Chinese method achieved a higher accuracy (73.16%) than the Indonesian method (66.84%).

The primary novelty of this research is the demonstration that neither national standard alone is sufficient for a complex urban area like Bandung. Consequently, we proposed and validated a hybrid framework that integrates the strengths of both methods. This combined model yielded a superior validation rate of 79.21%, proving its efficacy in capturing the city's composite flood risk profile.

These findings suggest several actionable paths forward. We recommend that Indonesian disaster management agencies (BNPB/BPBD) consider this hybrid assessment framework for developing new high-resolution flood risk maps. Such maps could serve as a foundational tool to help guide the strategic revision of local spatial planning regulations and prioritize infrastructure investments, particularly in Bandung's high-risk central-eastern corridor. Looking ahead, a significant opportunity for improvement lies in enhancing these risk assessments by integrating more dynamic physically based models. Future studies should therefore focus on incorporating detailed hydrodynamic and hydraulic modeling to move beyond static indices and better capture the complex physical processes of flooding. This technical advancement, combined with formalizing the "Penta-helix" multi-stakeholder collaboration and refining community capacity (IKM/IKD) assessments at a higher spatial resolution, would provide a more robust and adaptive flood management strategy.

6. Declarations

6.1. Author Contributions

Conceptualization, A.A.K., R.D.W., X.L., and K.S.P.; methodology, A.A.K., R.D.W., K.S.P., P.K., and R.S.; software, A.N.W., I.F.H., and R.S.; validation, A.N.W. and I.F.H.; formal analysis, A.A.K., K.N.P., P.K., and A.N.W.; investigation, A.N.W. and I.F.H.; resources, P.K., E.R.P., A.F., R.M., and K.I.; data curation, A.N.W., A.F., R.M., and K.I.; writing—original draft preparation, A.A.K., R.D.W., P.K., K.S.P., E.R.P., A.F., R.M., and K.I.; writing—review and editing, A.A.K., P.K., A.N.W., and I.F.H.; visualization, A.N.W. and I.F.H.; supervision, A.A.K., R.D.W., P.K., and K.S.P.; project administration, P.K. and E.R.P.; funding acquisition, R.D.W. and P.K. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding

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6.5. Conflicts of Interest

The authors declare no conflict of interest.

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